

COMPARISON OF BULLETS USING THE ELEMENTAL COMPOSITION OF THE LEAD COMPONENT

*Ernest R. Peele, Donald G. Havekost, Charles A. Peters,
John P. Riley and R. C. Halberstam*

FBI Laboratory
Washington, D. C.

Robert D. Koons

FBI Laboratory
Quantico, Virginia

Elemental analysis and comparison of the lead component of projectiles from shooting victims and crime scenes to the lead component of bullets associated with suspects has been a useful forensic tool for over 25 years (Lukens *et al.* 1970; Brunelle *et al.* 1970; Gillespie and Krishnan 1969; Lukens and Guinn 1971; Pro *et al.* 1965). Lead compositional analysis is especially valuable in situations where a firearm is not recovered, the crime scene bullet is too mutilated for firearms identification, or the firearm cannot be associated with the suspect. Methods which have been suggested for compositional analysis of bullet lead include neutron activation analysis (NAA), atomic absorption spectroscopy, spark source mass spectrometry, and inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Lukens *et al.* 1970; Brunelle *et al.* 1970; Haney and Gallagher 1975a,b; Peters *et al.* 1988). Presently, the methods used in the FBI Laboratory for the compositional analysis of bullet lead are NAA and ICP-AES. These analytical techniques have been accepted in courts throughout the United States.

During the past 25 years, much analytical data has been collected on bullet lead from known sources. Study of this data has produced a number of conclusions which form the basis for deriving opinions concerning comparison of bullet lead compositions. Primary among these is that not all bullets have the same composition, even those which are physically similar. Over the years, results of analyses of many samples in the FBI Laboratory have demonstrated that many different distinguishable compositions of bullets have been produced and those being produced now continue to display compositional variation. Second, by increasing the number of element concentrations determined, the lead can be more specifically characterized and, hence, more distinguishable compositions can potentially be identified. Third, if two bullets are produced from the same homogenous source of lead, then they will have analytically indistinguishable compositions.

The bullet manufacturing process begins by heating a quantity of lead until it melts. While molten, additives are mixed in and major impurities are removed. Smaller quantities of the modified lead are removed and allowed to cool. These smaller quantities are then extruded into a "bullet wire" the diameter of which is dictated by the caliber of the finished product. This wire is chopped to length and, either immediately or at some later date, the pieces are formed into bullets, loaded into cartridges, and packed into boxes (Fairchild 1971; Petty 1980) This box is the commodity which is sold to the consumer and is the unit of interest to the forensic scientist. However, the manufacturing process is the determining factor in the elemental composition of bullets loaded into the cartridges in each box. Previous studies have concentrated upon either the development of analytical methods or the differences among manufacturers and types of bullets (Lukens *et al.* 1970; Haney and Gallagher 1975a, b; Peters *et al.* 1988; Brandone and Piancone 1984; Blacklock and Sadler 1978; Guinn 1982, 1983; Guinn *et al.* 1987; Guy and Pate 1973), but the variability within a production run or among the bullets in a single box of cartridges has not been addressed in a comprehensive study. Such information is needed for proper interpretation of similarities in elemental composition among evidentiary samples.

This report presents the results of an FBI Laboratory study concerning the compositional variability of bullet leads from four major U. S. manufacturers. Replicate samples from all bullets in multiple boxes of cartridges from each of these manufacturers were analyzed. The goal of this study was to define the variability in element composition within individual bullets, among bullets within boxes of cartridges, among boxes packaged on the same date, among boxes packaged on different dates, and among boxes from the different manufacturers.

MATERIALS AND METHODS

Sample Selection

For this study, full boxes of .38 caliber cartridges loaded with 158 grain, round nose bullets of four brands (Cascade Cartridge Industries (CCI), Federal, Remington, and Winchester) were purchased from commercial ammunition suppliers. For each brand, four boxes of cartridges bearing three different lot numbers (indicating different assembly and packaging dates) were obtained. A fifth box of Winchester ammunition was obtained when it was determined that the bullets in one of the original boxes were a different alloy from the bullets in the other three boxes. Conversations with the manufacturer indicated that this alloy was only marketed for a limited time. The box containing different alloy bullets was not included in the analytical comparison. Production information for the bullets used in this study is shown in Table 1.

Sample Preparation

The nose portion of each bullet was used for most of the analyses. The lead nose of each bullet was quartered using a pair of metal cutters. Three of the quarters were randomly selected for analysis. These samples were cleaned by cutting away surface contamination, result-

ing in an approximately 120 mg piece from the interior of each quarter. Each sample was flattened by placing it between two steel plates and subjecting the "sandwiched samples" to about 20,000 psi pressure in a hydraulic press. The plates were equipped with a compartmented spacer for simultaneous uniform flattening of multiple samples to a thickness of approximately 0.3 mm. The samples were removed from the press and a circular sample weighing about 15 mg was punched from each flattened sample. These small circular samples were accurately weighed using an electronic microbalance and packaged and labeled for analysis by NAA. The remaining portion of each sample was similarly weighed and placed in a pre-labeled sample tube for subsequent dissolution and analysis by ICP-AES.

NAA Analytical Procedure

Samples were heat sealed between two sheets of polyethylene and transported to the National Institute for Standards and Technology (NIST) research reactor facility for irradiation. Analytical sets of 25 bullets (75 samples) along with triplicate samples of NIST SRM 2416 and in-house internal standards as needed were exposed to a thermal neutron flux of 2.8×10^{13} neutrons/cm²-sec for 5 minutes. Following irradiation and a cooling period of several hours, samples were radioassayed using a Canberra Ge(Li) detector coupled to a Nuclear Data 6620 multichannel analyzer. Element concentrations were determined by comparing the gamma ray spectral results from each bullet sample with those from the SRM 2416 standards. The appropriate radioassay parameters are given in Table 2.

ICP-AES Analytical Procedure

Details of the dissolution and ICP-AES analysis have been reported previously (Peters *et al.* 1988), so are only briefly summarized here. The 100 mg samples were placed into 15 ml polypropylene tubes to which 10 ml of 20% nitric acid was added. The tubes were capped and placed into an oven at 80°C for three hours. The tubes were then removed from the oven, allowed to cool, and 0.010 ml of 49% HF added. The tubes were recapped and the contents mixed by vortexing. Standards were prepared by accurately weighing 10 g of 99.9999% lead (Alfa Products, Danvers, MA) and 10 g of SRM 2416 bullet lead into separate 1000 ml Erlenmeyer flasks. To each flask was added 400 ml of deionized water and 200 ml of concentrated nitric acid. The flasks were heated on a hotplate at 140°C until the lead dissolved. The solutions were cooled, transferred quantitatively to 1000 ml volumetric flasks and brought to volume with deionized water. The high purity lead solution was used to dilute

Table 1. INFORMATION CONCERNING MANUFACTURERS OF BULLETS USED IN THIS STUDY.

Manufacturer	Plant Location	Packaging Dates ^a
Cascade Cartridge	Lewiston, Idaho	Box 1 05/13/83
		Box 2 12/27/85
		Box 3 04/06/86
		Box 4 12/27/85
Federal	Anoka, Minnesota	Box 1 12/13/84
		Box 2 09/23/83
		Box 3 08/15/85
		Box 4 12/13/84
Remington	Lonoke, Arkansas	Box 1 04/27/72
		Box 2 04/27/72
		Box 3 11/17/81
		Box 4 04/27/85
Winchester	East Alton, Illinois	Box 1 02/28/75
		Box 2 01/29/76
		Box 3 ^b 06/05/81
		Box 4 01/29/76
		Box 5 07/05/75

^a Boxes bearing the same packaging date are from the same lot number.

^b Not included in this study, different alloy than other Winchester samples (new alloy used for one year period).

**Table 2. NEUTRON ACTIVATION ANALYSIS
ACTIVATION AND RADIOASSAY
PARAMETERS.**

Sample Irradiation

Facility	NIST RT-4
Neutron Flux	2.8×10^{13} n/cm ² -sec
Time	5 min

Standard Data for SRM 2416

	Composition %	Isotope	n, τ Product	
			Half-life hours	Energy KeV
Copper	0.065	⁶⁴ Cu	12.8	511
Antimony	0.79	¹²² Sb	64.8	564
Arsenic	0.056	⁷⁶ As	26.3	559

Detector Specifics

Type	Coaxial Germanium, 91.3 cm ³
Efficiency	19% for ⁶⁰ Co at 1332 KeV
Resolution	1.77 eV FWHM for ⁶⁰ Co at 1332 KeV
Radioassay Time	15 min each for samples and standards

the SRM 2416 standard to produce standards of intermediate composition for analysis of bullet leads. Aqueous standards made from 1000 µg/ml Sn standard solution (Fisher Scientific) were used for calibration for the bullet lead samples having high tin contents. Element concentrations were determined using a Plasma II ICP-AES (Perkin-Elmer) with the instrument operating conditions given previously (Peters *et al.* 1988). Well-characterized bullet lead standards were included with each set of samples to insure analytical accuracy.

RESULTS AND DISCUSSION

In this study, 7 to 9 analytical determinations were made on each of triplicate samples of lead from 800 bullets resulting in nearly 20,000 element concentration measurements. Because of space limitations, these results are presented in summary form. Elemental concentrations are referred to by analytical method and element symbol, that is, NAACU refers to copper concentration determined using NAA.

Analytical Accuracy

This study provides a comparison of NAA and ICP-AES results for Cu and Sb using a large number of samples analyzed by the two independent analytical methods. For the samples in this study, the equations for linear regression of the ICP-AES results on the NAA results (expressed as µg/g) are as follows:

ICPSB = 1.028*NAASB - 161.3 with r = 0.998, for all 2400 samples

ICPSB = 0.985*NAASB + 71.1 with r = 0.995, for those 1200 samples having Sb at less than the one percent level

ICPCU = 1.012*NAACU - 3.231 with r = 0.995, for all 2400 samples

The slope values in these equations are equal to the ideal value of 1 and the y-intercept values are equal to the ideal value of 0 within the measurable analytical uncertainties, thus indicating the generally excellent agreement between the two techniques. The accuracy of NAA for Sb, Cu, and As has been well established and that of ICP-AES has previously been demonstrated for several elements including the six in this study (Peters *et al.* 1988).

Compositional Variation within Bullets

In a limited study, 10 bullet leads from a single box were subdivided into three portions - nose, middle, and base. Each portion was analyzed in triplicate. Based on the nine samples of each bullet, all measured element concentrations were found to be randomly distributed throughout the bullets within the analytical uncertainties. Based on the lack of measurable differences in composition within these bullets and 25 years of similar measurements in the FBI Laboratory, three replicates from the nose portion of each bullet lead were used in the full study.

The triplicate samples of each bullet lead were used to calculate a coefficient of variation (COV) for each element as a measure of the compositional variation within bullets. The mean within-bullet COV values and the ranges in compositions of the four brands are shown in Table 3. The within-bullet COVs for NAASB, ICPSB, NAACU, and ICPCU are in the 1 to 3% range, over the wide composition ranges for these elements in the four brands. The within-bullet COVs for ICPAG are in the 1 to 3% range across all brands, all of which contain Ag in similar concentration ranges. The within-bullet COVs for NAAAS and ICPBI increase as the concentration decreases, being 1 to 3% at higher levels, and about 5% at lower levels. These precision values are similar to those resulting from repeated analysis of homogeneous NIST standard reference leads, indicating that the bullets in this study were compositionally homogeneous within the instrumental analytical uncertainties.

Compositional Variation within Boxes

Examination of the data indicated that in all but one box of cartridges, there were more than one obvious

Table 3. WITHIN BULLET VARIABILITY MEASUREMENTS. VALUES REPRESENT THE MEAN COEFFICIENT OF VARIATION OF TRIPPLICATE MEASUREMENTS OF EACH BULLET AND THE RANGE IN CONCENTRATIONS FOR ALL BULLETS OF EACH BRAND.

Brand		NAASB/ICPSB	NAACU/ICPCU	NAAAS/ICPAS	ICPAG	ICPBI	ICPSN
CCI	COV, %	1.6/1.7	2.5/1.7	2.8/---	1.9	3.8	---
	Range, ppm	23800 - 29900	97 - 381	82 - 546	18 - 69	56 - 180	
Fed	COV, %	1.2/1.5	1.9/1.5	1.6/3.7	2.2	6.7	2.5
	Range, ppm	25700 - 29000	233 - 329	1127 - 1645	14 - 19	30 - 91	1100 - 2880
Rem	COV, %	0.8/1.5	1.6/1.5	3.7/---	1.8	3.4	---
	Range, ppm	5670 - 9620	62 - 962	4 - 272	21 - 118	67 - 365	
Win	COV, %	1.0/1.9	2.1/2.1	5.7/---	1.9	4.4	---
	Range, ppm	2360 - 6650	54 - 470	5 - 165	14 - 61	35 - 208	

distinct lead composition. Therefore, mean and standard deviations of elemental concentrations within boxes of bullet lead have little meaning, so they were not calculated. Instead, within each box of cartridges, the lead samples were subdivided into compositional groups constructed as follows. The mean element concentrations of the first and second bullets in a box were compared using the range based on the triplicate analysis or a predetermined analytical uncertainty, whichever was larger, as a criterion. If they overlapped in all elements, they were placed into a compositional group, otherwise they were placed into separate groups. The next bullet was then compared to these two, and so on, in the same manner until all bullets in a box were placed into compositional groups. Each bullet within a group is analytically indistinguishable for all elements measured from at least one other bullet in the group and is distinguishable in one or more elements from all bullets in any other compositional group. It should be noted that occasionally in groups containing more than two bullets, chaining of bullets occurs. That is, two bullets may be slightly separated from each other, but each be indistinguishable from a third bullet, resulting in all three being included in the same compositional group.

The mean element concentrations and number of bullets in each compositional group within each box of cartridges from this study are shown in Tables 4-7. The number of compositional groups per box varies from one brand to another, but is fairly consistent for a given brand. The average number of compositional groups per box is 2.0 for Federal, 3.5 for CCI, 6.0 for Remington, and 12.5 for Winchester. The number of bullets in each compositional group varies widely, even within a single box. The number of compositional groups within each box, their ranges in elemental concentrations, and the number of bullets per compositional group reflect the production and packaging processes in effect at each

manufacturing plant at the time of production of the boxes used in this study. The fact that there are distinguishable compositional groups of lead, even within a single box, has significant impact on interpretation of results in forensic cases. This interpretation must be undertaken with an understanding of the underlying production and packaging processes which lead to the observed lead compositional distributions.

The variation in element concentrations within compositional groups is one factor which determines the ability to distinguish between bullet leads from different compositional groups. Of the 74 compositional groups found in this study, 19 contain more than 10 bullets (30 samples). These groups are large enough to provide reliable estimates of the overall compositional group variabilities. As a measure of the elemental variation within compositional groups, we have calculated the group cov for each element for these 19 compositional groups. These results are shown in Figure 1, where the group cov by element is plotted against the mean group element concentrations. Elemental variations within a compositional group, shown in Figure 1 are, on average, slightly greater than the within-bullet COVS, shown in Table 3. If the only contributor to cov were the analytical precision, the within bullet and within compositional group COVS should be equal. The slightly larger variability within compositional groups demonstrates that a portion of the group variability may reflect true heterogeneity among the bullets within a compositional group. Complete explanation of the causes of variation among bullets within a compositional group can only be determined by analysis of samples removed during the manufacturing process. Although not a goal of this study, such information has been gathered over many years from samples removed from cartridge assembly lines and analysis of many boxes of bullet leads in the FBI Laboratory.

Table 4. CCI BULLET LEAD COMPOSITIONAL GROUPS. MEAN ELEMENT CONCENTRATIONS IN $\mu\text{g/g}$.

GROUP	NOBULLETS	NAASB	NAACU	NAAAS	ICPBI	ICPAG
1-Box1	1	27500	141	369	128	23
2-Box1	17	25300	166	405	109	24
3-Box1	23	26000	204	422	107	24
4-Box1	9	25700	286	497	98	19
5-Box2	5	25400	153	411	88	28
5-Box4	4	25500	157	396	82	28
6-Box2	1	26200	229	325	93	34
6-Box4	1	25500	223	321	83	33
7-Box2	44	27200	340	138	147	38
7-Box4	43	28000	349	139	145	39
8-Box3	9	27300	179	93	170	57
9-Box3	40	26800	209	172	124	52
10-Box3	1	27600	221	132	77	68
11-Box4	2	27000	103	538	65	18

Compositional Variation Among Boxes of the same Brand

The compositional variation of bullets among boxes of cartridges of the same type and brand is one of the most significant factors in determining the forensic implication of compositional association. Compositional group overlaps from one box to another, where they occur, should be recognized and explanations sought. The assembly and packaging dates, locations and respective manufacturers of boxes of cartridges whose bullet leads were analyzed in this study are shown in Table 1. The range of assembly and packaging time is relatively short for three of the manufacturers. CCI has a three year range, Federal a two year range, and Winchester an 11 month range; Remington is the only brand with a large spread among packaging dates, 12 years.

For both the CCI and Remington leads, shown in Tables 4 and 6, there are no compositional group overlaps among bullets from boxes with different assembly and packaging dates. All indistinguishable compositional

group pairs occur between boxes with common production dates. In both of these brands, overlapping compositional groups consist of one large group of bullets and several smaller groups or single bullets.

The elemental compositions of the Federal bullet leads, shown in Table 5, follow a different behavior. Box #3 of Federal is the only box of cartridges in this study containing a single compositional group. The remaining three boxes contain two distinct compositional groups common to all three boxes. Boxes #1 and #4 bear the same production and packaging date, but box #2 was packaged 15 months prior to the other two. There are two possible explanations for the overlapping compositions for bullets packaged on different dates. Overlapping compositions occur either by coincidence or because the bullets originated from the same analytically homogeneous source of lead. From our previous experience and discussions with Federal Cartridge Corporation representatives, a reasonable explanation for multiple boxes containing indistinguishable lead compositions is that the cartridges were produced from a

Table 5. FEDERAL BULLET LEAD COMPOSITIONAL GROUPS. MEAN ELEMENT CONCENTRATIONS IN $\mu\text{g/g}$.

GROUP	NOBULLETS	NAASB	NAACU	NAAAS	ICPBI	ICPAG	ICPSN
1-Box1	18	27400	268	1320	61	16	1760
1-Box2	13	27300	271	1340	61	16	1740
1-Box4	19	27300	270	1340	58	16	1720
2-Box1	32	27300	294	1470	67	17	2490
2-Box2	37	27400	302	1500	66	16	2360
2-Box4	28	27300	297	1490	64	17	2430
3-Box3	50	27600	248	1230	71	16	2470
4-Box4	3	27900	247	1280	62	17	1180

**Table 6. REMINGTON BULLET LEAD COMPOSITIONAL GROUPS.
MEAN ELEMENT CONCENTRATIONS IN $\mu\text{g/g}$.**

GROUP	NOBULLETS	NAASB	NAACU	NAAAS	ICPBI	ICPAG
1-Box1	6	5800	727	80	197	32
1-Box2	7	5840	730	83	198	33
2-Box1	10	6020	608	112	192	33
2-Box2	9	6040	612	111	190	34
3-Box1	26	6300	508	141	185	35
3-Box2	30	6320	513	142	182	35
4-Box1	4	6450	458	162	182	35
4-Box2	3	6510	464	161	176	36
5-Box1	1	8050	66	220	175	36
6-Box1	3	8060	68	263	168	37
7-Box2	1	7640	200	168	158	39
8-Box3	1	7710	143	105	124	32
9-Box3	1	7820	172	98	116	30
10-Box3	8	8000	147	56	78	109
11-Box3	1	8460	177	128	122	29
12-Box3	6	8600	144	115	80	87
13-Box3	15	8890	197	145	122	28
14-Box3	16	9420	203	165	117	28
15-Box3	2	9170	269	169	124	27
16-Box4	1	7080	951	17	221	32
17-Box4	11	7190	419	13	154	24
18-Box4	13	7420	447	44	330	44
19-Box4	3	8080	269	20	334	44
20-Box4	22	8190	233	6	120	23

common lead production source and component storage before cartridge loading. The small concentration ranges exhibited by Sb, Ag, and Bi in Federal lead in this study are also factors limiting the discrimination capability.

The compositional group distributions across boxes of Winchester bullets exhibit a third pattern of behavior. The Winchester bullets are characterized by the presence of many different compositional groups within each box. Explanations for this may include smaller production runs and more frequent component addition to the melted lead. The comparatively large number of compositional groups per box of Winchester lead offers a means of determining whether cross-box compositional overlaps occur as a result of coincidental production of indistinguishable composition lead on two dates or by a common production source. If one compositional group is found in common between two boxes, it may be attributable to coincidence. However, when multiple groups are found in common, a common production source of lead components is more likely. Winchester boxes #2 and #4, which bear the same assembly and packaging date have respectively 14 and 15 compositional groups. Of these, nine are common to both boxes, an expected occurrence given the same packaging date for these two boxes. As

in most Winchester compositional groups, these groups each contain only one or several bullets. However, boxes #4 and #5 also have two compositional groups in common. The compositional groups in box #4 that match those in box #5 are different than the groups that match those in box #2. The packaging dates of boxes #4 and #5 differ by 7 months. The facts that there are two group overlaps and that there are five elements with wide ranges and good analytical precision in Winchester lead, make it unlikely that the overlap is a coincidental occurrence. Discussion with Winchester personnel and past experience indicate that the compositional group overlaps for these two boxes are reasonably explained by a common production source and storage of components before cartridge loading.

Compositional Variation across Brands

The ranges of measured element concentrations for each brand are shown graphically in Figure 2. Several observations are apparent from this data. Nominal Sb content, a compositional factor intentionally controlled by the lead manufacturer, is 0.5, 0.75, 2.75, and 2.75% for Winchester, Remington, Federal, and CCI respec-

tively. The range in Sb concentrations relative to the mean is greater in Winchester than other brands. For example, a range of 0.24 to 0.66% Sb was found in the lead from a single box of Winchester cartridges. The Federal bullet leads in this study are much different from the other brands in that they contain much higher Sn and

As concentrations. The ranges in concentration of Cu and Ag are less in Federal than in the other brands. In summary, the four brands of bullets in this study are each compositionally distinguishable from each other. However, it is our experience that each manufacturer uses several alloys of lead across their product line re-

**Table 7. WINCHESTER BULLET LEAD COMPOSITIONAL GROUPS.
MEAN ELEMENT CONCENTRATIONS IN $\mu\text{g/g}$.**

GROUP	NOBULLETS	NAASB	NAACU	NAAAS	ICPBI	ICPAG
1-Box1	4	2440	270	11	126	30
2-Box1	1	3610	178	54	99	35
3-Box1	1	4280	98	32	84	46
4-Box1	2	4320	317	37	128	35
5-Box1	24	4330	156	33	100	52
6-Box1	2	4100	171	32	101	54
7-Box1	2	4520	469	7	199	44
8-Box1	1	4520	316	22	156	34
9-Box1	1	4770	176	18	118	21
10-Box1	1	5280	70	22	48	14
11-Box1	2	5410	207	26	53	21
12-Box1	7	5390	187	59	51	22
13-Box1	1	5560	141	24	111	20
14-Box1	1	6570	112	28	84	22
15-Box2	3	3830	205	37	136	53
15-Box4	6	3850	210	37	149	56
16-Box2	8	4080	61	14	132	35
16-Box4	6	4120	61	14	133	36
17-Box2	4	4200	176	158	150	39
17-Box4	4	4260	177	158	156	40
18-Box2	4	4200	162	84	128	36
18-Box4	1	4230	161	84	138	38
19-Box2	6	4220	154	67	117	36
19-Box4	2	4380	163	67	114	36
20-Box2	1	4460	90	16	128	35
20-Box4	2	4480	92	18	135	36
21-Box2	5	4470	130	40	131	47
21-Box4	2	4470	131	40	134	46
22-Box2	4	4530	214	96	114	30
22-Box4	4	4610	214	96	129	31
23-Box2	1	4540	234	72	140	33
24-Box2	9	4770	401	28	141	32
24-Box4	4	4840	408	28	145	33
25-Box2	1	4770	168	13	163	57
26-Box2	1	4810	278	106	121	29
27-Box2	2	4980	404	57	116	28
28-Box2	1	5540	409	8	123	29
29-Box4	1	4460	230	49	122	32
30-Box4	1	4510	186	36	126	43
31-Box4	1	4870	325	75	129	29
32-Box4	13	4950	322	8	98	42
32-Box5	24	5030	327	8	100	43
33-Box4	1	5360	316	35	148	38
34-Box4	2	5590	226	32	103	44
34-Box5	4	5630	226	32	109	44
35-Box5	6	4470	387	14	116	45
36-Box5	8	4570	299	9	97	48
37-Box5	2	5120	220	29	114	43
38-Box5	3	5250	402	22	128	40
39-Box5	3	5460	301	26	121	39

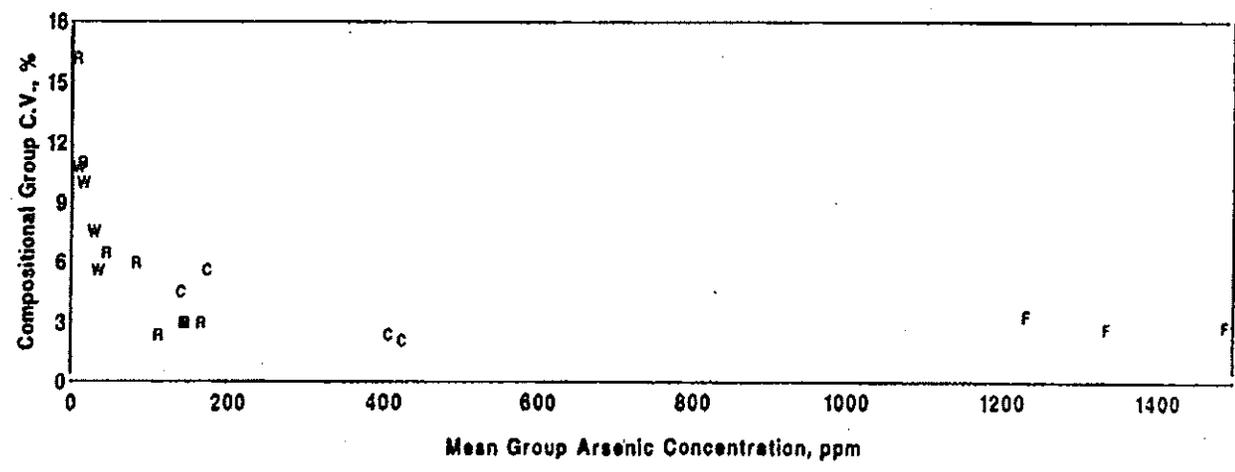
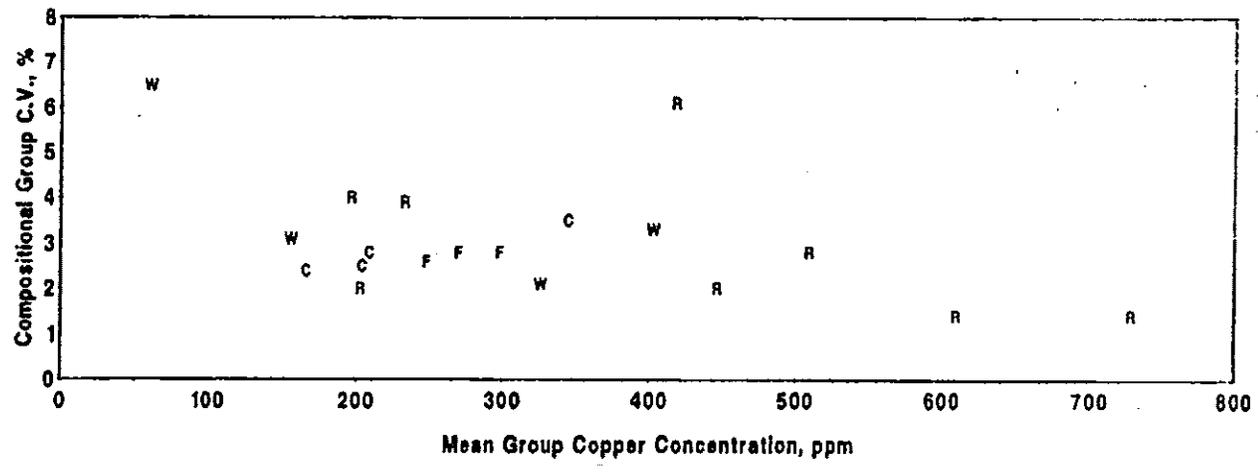
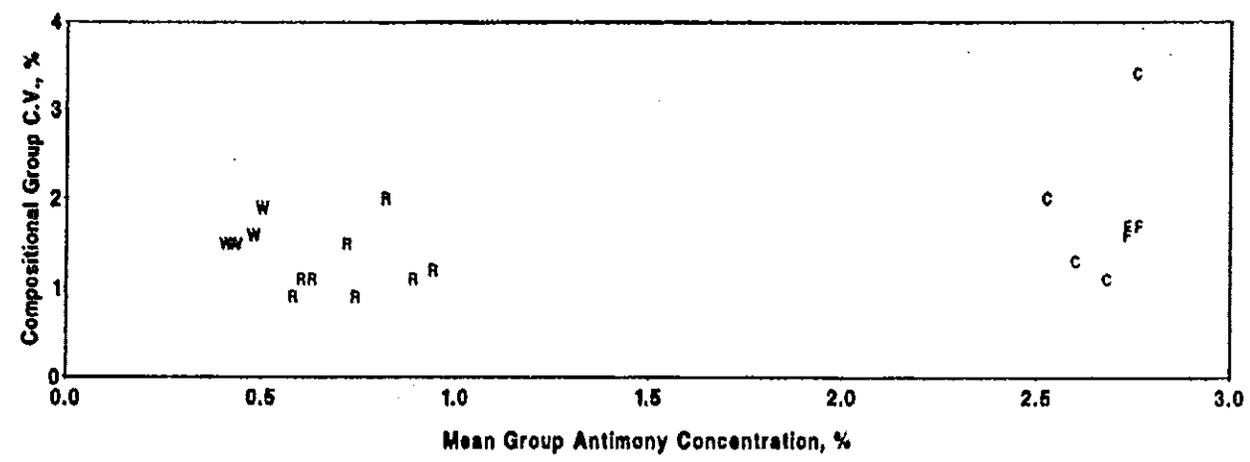


Figure 1. Element concentration statistics for the 19 compositional groups containing more than 10 bullet leads.

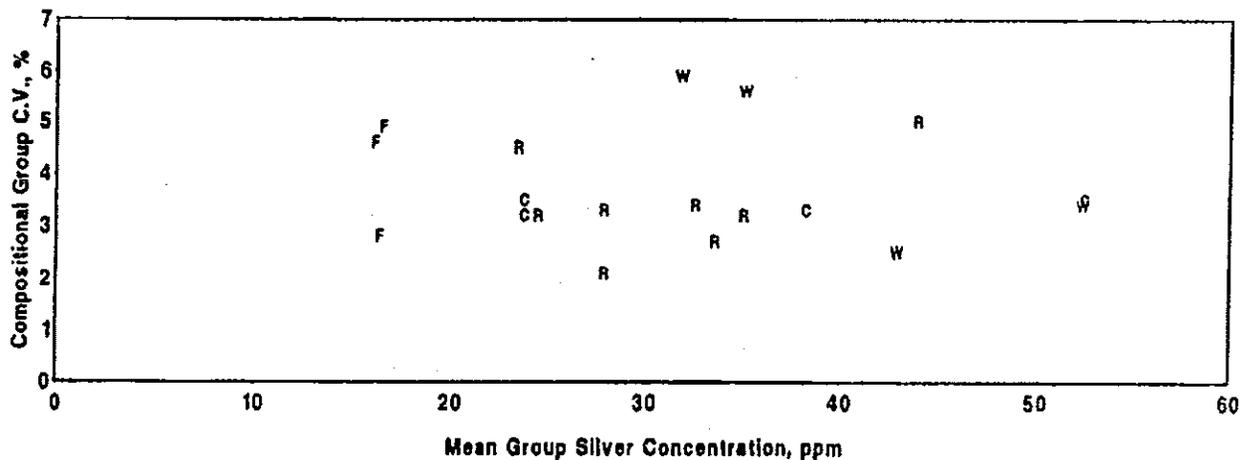
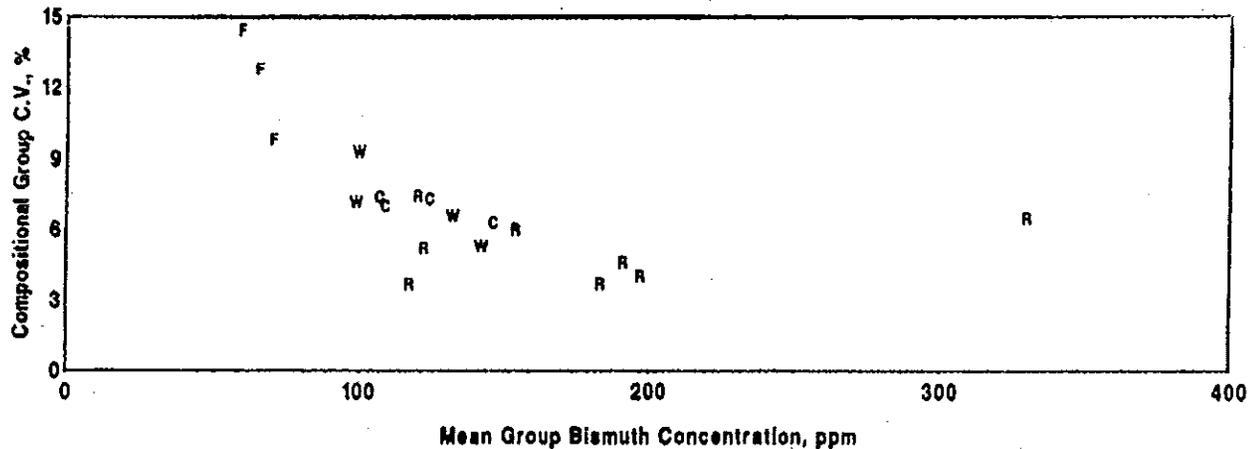


Figure 1 — Continued. Element concentration statistics for the 19 compositional groups containing more than 10 bullet leads.

sulting in wider ranges of elemental compositions than those seen in this study. Therefore, it is generally not possible to identify the manufacturer of a single bullet based on the bullet's elemental composition.

Discriminating Capabilities of Individual Elements in Bullet Lead Comparisons

Two bullets must be analytically indistinguishable in all measured elements before they can be attributed to a common source. However, the relative importance of individual elements for source discrimination depends upon the measured homogeneity of the lead compared to the across-product range. In this study, all elements provide useful data for grouping. The relative importance of the elements for providing discrimination of lead sources decreases in the order: Cu, As > Sb > Bi, Ag. Tin is not included in this sequence because of its limited detectability in three brands of the lead in this study. However,

Sn is very important in defining compositional groups in the Federal lead, where it was high enough to be accurately determined. Although Bi and Ag provide the least discrimination, they are useful in support of group divisions based on the other elements in cases where intergroup differences are not large. The more elements which are measured and the greater their ratio of range to analytical precision, the better the discrimination capability and the less the potential for coincidental overlaps.

SUMMARY

Accurate, reproducible elemental concentration determinations in bullet leads can be obtained using both NAA and ICP-AES methods. In this study, the elemental compositions of the lead component of all cartridges from 16 boxes of cartridges from four manufacturers were determined. Element concentrations in individual bullet leads are generally homogeneously distributed

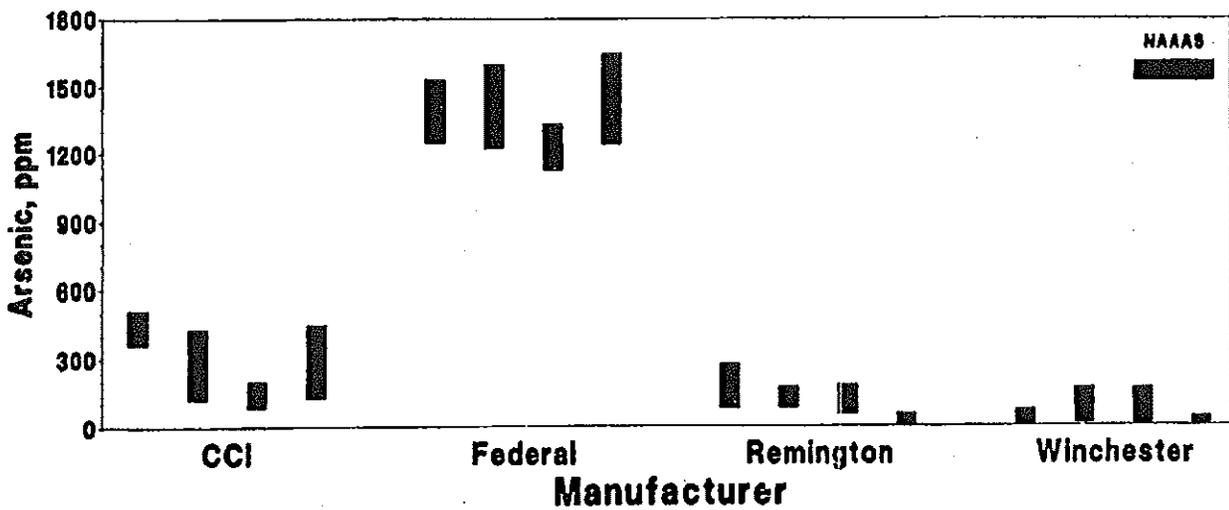
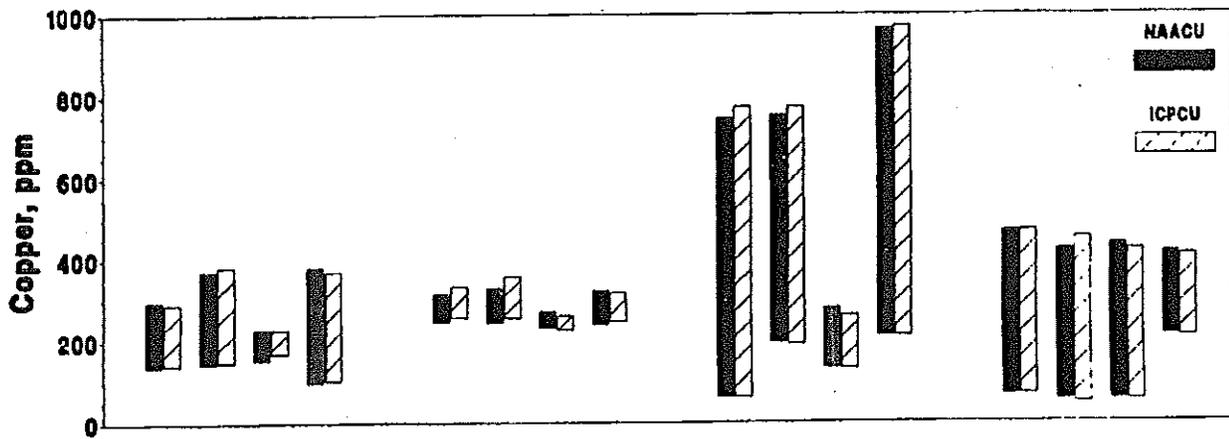
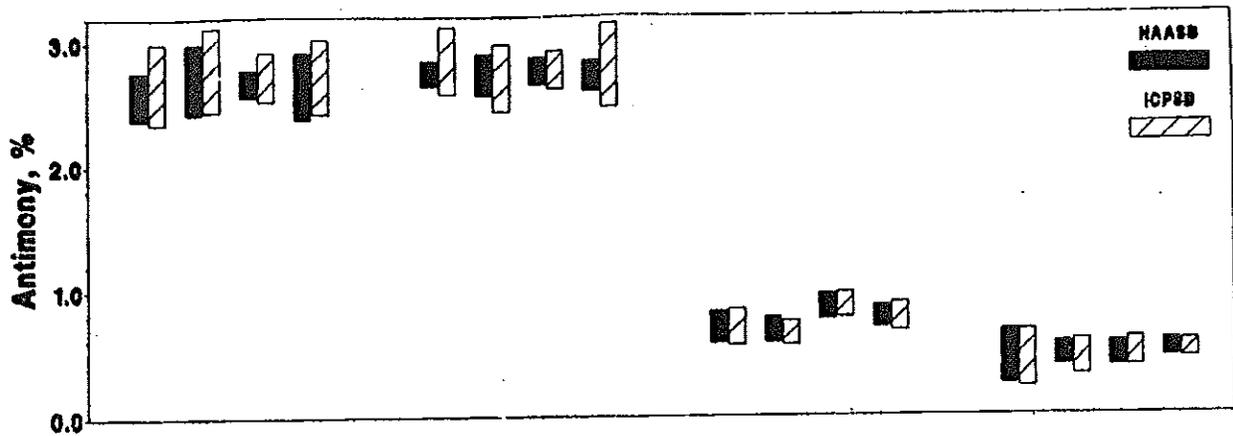


Figure 2. Range in element concentrations in bullet leads from four boxes from each of four brands.

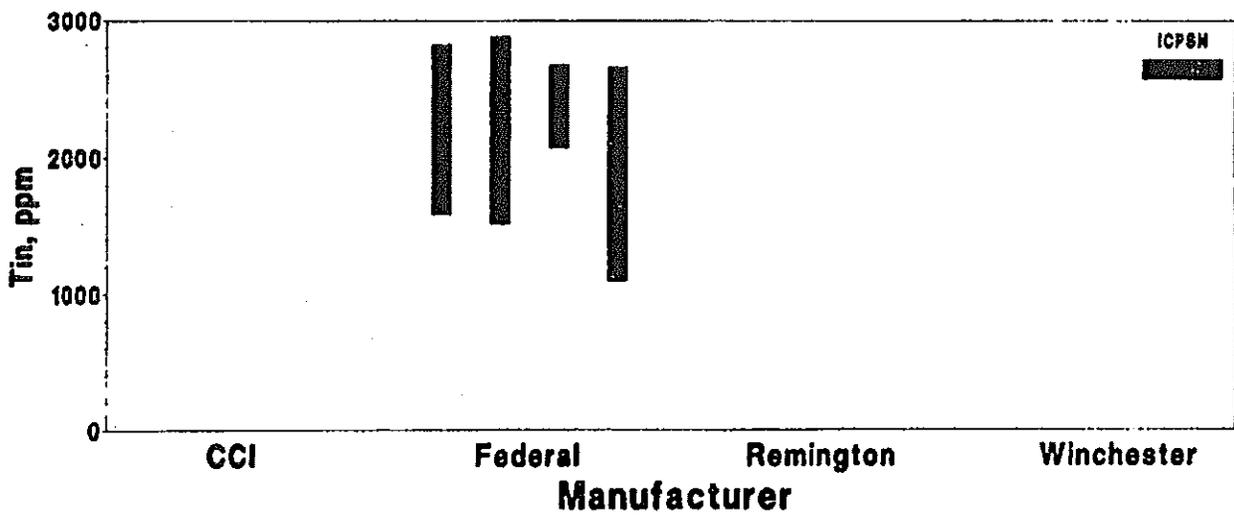
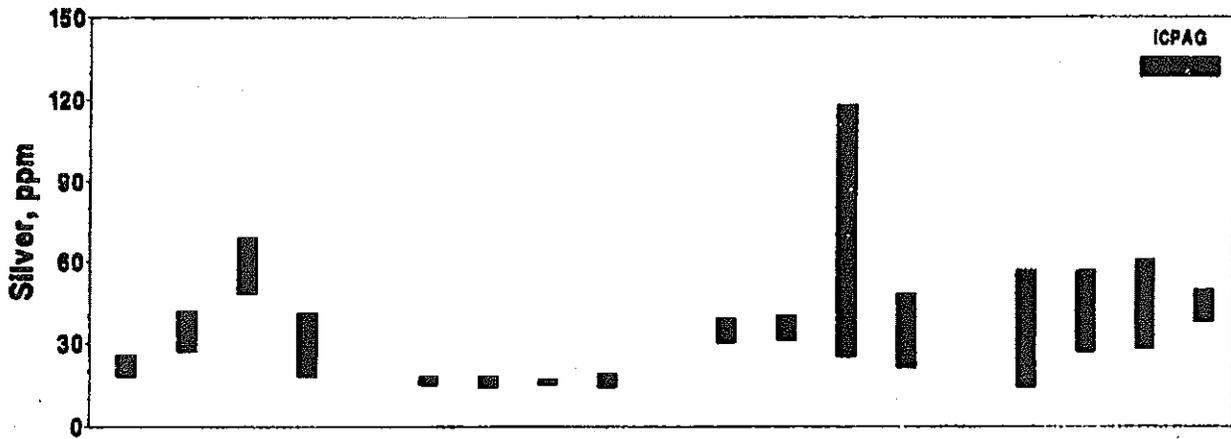
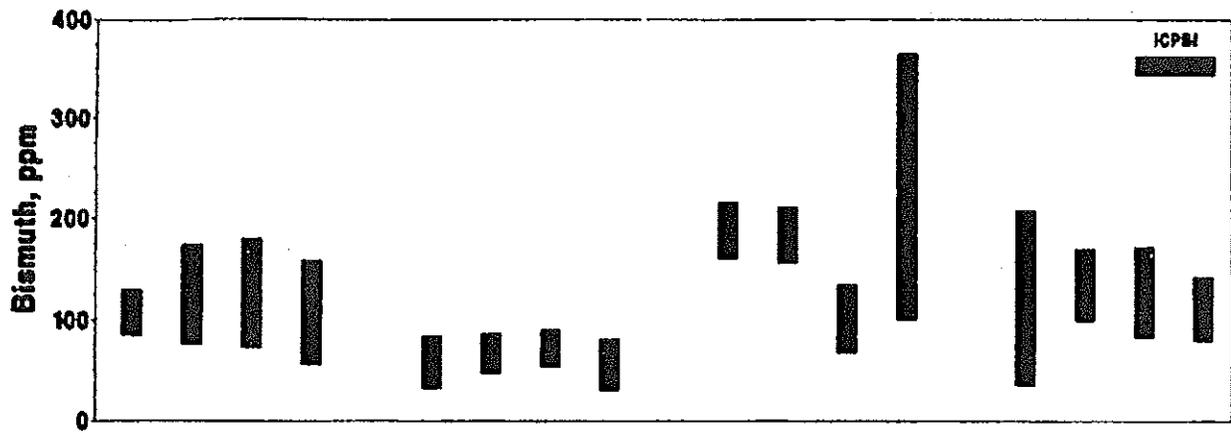


Figure 2 — Continued. Range in element concentrations in bullet leads from four boxes from each of four brands.

within the analytical uncertainty of NAA and ICP-AES. The bullets within a single box of cartridges can be subdivided into a number of distinct compositional groups. These groups are analytically distinguishable from one another in one or more element concentrations. Further, the number of compositional groups per box varies from one brand to another, reflecting differences in the manufacturing processes. No cross-brand compositional group overlaps were found in this study. Compositional group overlap among bullet leads from cartridges of the same brand are generally expected from boxes with the same assembly and packaging dates and not expected from boxes with widely different dates. Results from this project and our previous experience indicate that when compositional overlap between boxes occurs, it is more reasonable to expect the overlap from boxes of the same type and brand of bullet, packaged near the same date. The classifying power of the elements studied is, in general, Cu,As>Sb>Bi,Ag. Tin provides excellent discrimination for the Federal bullets in this study, which have high concentrations of this element.

This study demonstrates the compositional variation of bullets within boxes, from box to box of the same brand, and from brand to brand. As an illustration of forensic application of this approach, let us take an example of one bullet removed from a victim, five cartridges from a revolver, and 44 cartridges from a box associated with the suspect. Each bullet component of all these specimens is analyzed by NAA and ICP-AES. The composition of the bullet from the victim is analytically indistinguishable in all five elements determined from two bullets from the gun and twenty from the box. Two more bullets from the gun are compositionally indistinguishable from 10 others from the box. The last bullet from the gun is compositionally indistinguishable from seven others from the box. The seven remaining bullets from the box fall into two additional compositional groups. It is our opinion that these results are forensically significant in associating the victim, weapon, and suspect in this example.

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REFERENCES

- Blacklock, E. C. and Sadler, P. A. (1978).* Shot-gun pellet identification and discrimination, *Forens. Sci. Intern.* 12:109-117.
- Brandone, A. and Piancone, G. F. (1984).* Characterisation of firearms and bullets by instrumental neutron activation analysis, *Intern. J. Appl. Radiat. Isot.* 35:359-364.
- Brunelle, R. L., Hoffman, C. M. and Snow, K. B. (1970).* Comparison of elemental composition of pistol bullets by atomic absorption: preliminary study, *J. Assoc. Off. Anal. Chem.* 53:470-474.
- Fairchild, G. (1971).* U. S. ammo makers turn out cartridges by the billions, *Am. Rifleman* 119:28-30.
- Gillespie, K. A. and Krishnan, S. S. (1969).* Analysis of lead shot - a comparison of analyses using atomic absorption spectrophotometry and neutron activation analysis, *Canad. Soc. Forens. Sci. J.* 2:95-103.
- Guinn, V. P. (1982).* NAA of bullet-lead evidence specimens in criminal cases, *J. Radioanal. Chem.* 72:645-663.
- Guinn, V. P. (1983).* The elemental comparison of bullet-lead evidence specimens, In: *Chemistry and Crime* (Gerber, S. M., ed.), American Chemical Society, Washington, D. C., pp. 64-77.
- Guinn, V. P., Fier, S. R., Heye, C. L. and Jourdan, T. H. (1987).* New studies in neutron activation analysis, *J. Radioanal. Nucl. Chem.* 114:265-273.
- Guy, R. D. and Pate, B. D. (1973).* Studies of the trace element content of bullet lead and jacket material, *J. Radioanal. Chem.* 15:135-142.
- Haney, M. A. and Gallagher, J. F. (1973a).* Differentiation of bullets by spark source mass spectrometry, *J. Forens. Sci.* 20:484-500.
- Haney, M. A. and Gallagher, J. F. (1973b).* Elemental analysis of bullet lead by spark source mass spectrometry, *Anal. Chem.* 47:62-65.
- Lukens, H. R. and Guinn, V. P. (1971).* Comparison of bullet lead specimens by nondestructive neutron activation analysis, *J. Forens. Sci.* 16:301-308.
- Lukens, H. R., Schlesinger, H. L., Guinn, V. P. and Hackleman, R. P. (1970).* Forensic neutron activation analysis of bullet-lead specimens, U. S. Atomic Energy Commission Report GA-10141, 48 p.
- Peters, C. A., Havekost, D. G. and Koons, R. D. (1988).* Multielement analysis of bullet lead by inductively coupled plasma-atomic emission spectrometry, *Crime Laboratory Digest* 15:33-38.
- Petty, C. E. (1986).* American ammunition makers, *Am. Rifleman* 134:28-29,72,74.
- Pro, M. J., Schlesinger, H. L. and Hoffman, C. M. (1965).* Application of neutron activation analysis in criminalistics, U. S. Treasury Dept. Report, 96 p.